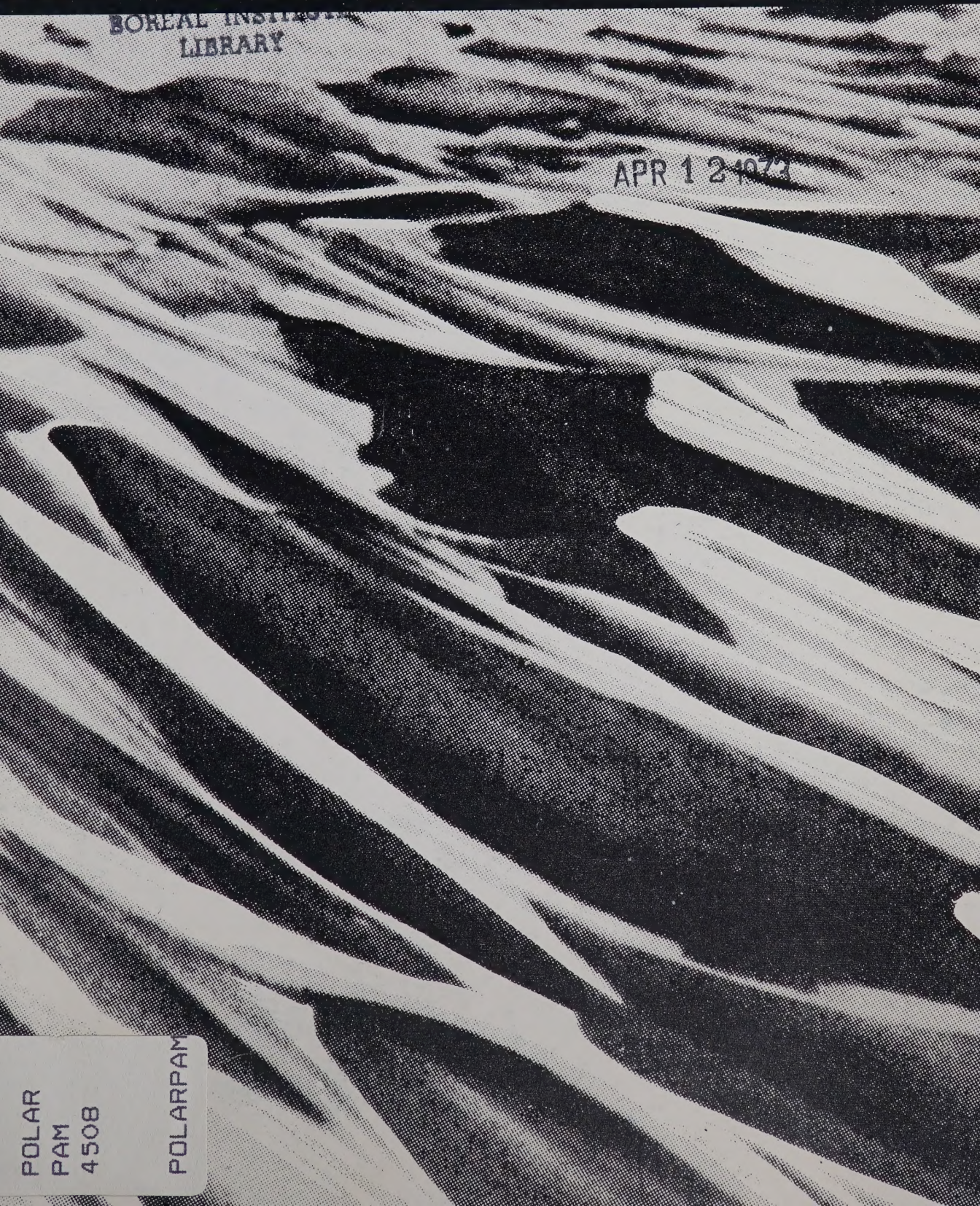
ENGINEERING FOR THE ARCTIC

A COMPENDIUM OF ACTIVITIES, FACILITIES AND EXPERTISE AT THE UNIVERSITY OF ALBERTA



This booklet is intended for the use and information of all individuals and organizations interested in engineering in the north. General enquiries may be sent to the Faculty of Engineering of The University of Alberta but specific enquiries should be addressed to the individuals named at the end of the appropriate description.

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ENGINEERING FOR THE ARCTIC

A Compendium of activities, facilities and expertise at The University of Alberta

Compiled and Edited by

G. S. H. LOCK

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PREFATORY NOTE

The continued development of the work described in the first edition of this booklet has rendered that description increasingly inaccurate: there is, therefore, good reason to compile a revised version. It was intended that the original booklet would be distributed to the two-hundred or so people and places known to be interested in arctic engineering: in fact, over five-hundred additional copies were requested. Thus this second edition is designed to satisfy the need for a current description of arctic engineering in the Faculty of Engineering, The University of Alberta.

The organization of the second edition is essentially the same as that used in the earlier version. The three main divisions—Geotechnology, Environmental Engineering and Resource Development—have been retained for pragmatic reasons. Within each division the listings have been revised as necessary, with the appearance of several new headings and subheadings. Bibliographies have been updated but they are not intended to be exhaustive. A Table of Contents has been added to give quicker access to the work and to provide an overall perspective.

INTRODUCTION TO THE FIRST EDITION

Research relevant to arctic engineering at The University of Alberta dates back to 1944 and 1945. At that time the first laboratory tests on this continent concerned with engineering characteristics of permafrost soils were conducted, and systematic surveys were initiated of the then current practices in engineering construction in permafrost areas of northwestern Canada. The results of these early studies were published in 1946.

The teaching of the principles of frost action in soils which are basic to problems of construction in arctic environments has even a longer history at this University. Such material was included in academic courses in Engineering as early as 1941, and they were the first of their kind in Canada.

Over the years, research and instruction concerning the behaviour of soils under freezing conditions have been continued without let-up, and the breadth of interest in arctic engineering has greatly increased within the engineering specialties. Major contributions to the development of improved construction practices and related problems in arctic areas have been made by our graduates who were first introduced to the problems through our instructional courses and research activities, and members of our academic staff have been involved in many projects in which advances were made in construction practices.

Concurrently, of course, many other organizations and individuals became involved in problems of the arctic, and have made their own independent contributions to the developing arctic technology. Particularly during the past decade interest in problems of arctic environments has expanded beyond engineering considerations, and it now is truly interdisciplinary involving many specialized areas some of which are far removed from engineering concepts.

Currently, in many instances, the need is for integrated approaches with team efforts involving the merging of expertise from several of the many special disciplines capable of useful contributions. It is therefore timely that we in the Faculty of Engineering at this University should record the variety, breadth and depth of our interests in problems of arctic engineering. By so doing, not only will it assist us in co-ordination of our own internal efforts, but it is to be hoped will also lead to increased co-operation and involvement with those from other disciplines concerned with the development of arctic areas.

R. M. Hardy
Dean of Engineering

August 1970

TABLE OF CONTENTS

GEOTECHNOLOGY

The mechanical properties of the materials composing the earth's surface, their relation to resource development, natural hazards, and the response of structures built upon them.

PROPERTIES OF ARCTIC SOILS AND ROCKS

Not only are certain surficial deposits peculiar to the Arctic but also changes in the temperature regime in soil and rock masses are responsible for complex behaviour when subjected to applied loads. The stress-strain-time behaviour of these natural materials has temperature-time parameters imposed upon it.

The design of structures such as highway embankments, pipelines, dams, and buildings requires a knowledge of the response of soils and rocks to changes in load and temperature. In order to perform the necessary calculations the constitutive relations which represents the mechanical behaviour of the materials are needed. Systematic investigations into the constitutive relations of arctic soils and rocks are being initiated. Special attention will be devoted to materials in their natural state and field studies are contemplated as an essential part of the programme.

Contact: S. Thomson

MECHANICS OF FROZEN GROUND PHENOMENA

Freezing and thawing of soil and rock is a dominant characteristic of weathering processes in the Arctic. Moreover the natural processes may be transformed by effects of activities associated with construction such as pipeline installations and highways.

It is generally recognized that thawing of permafrost is partticularly troublesome in northern development. Natural thawing is also associated with solifluction and several other periglacial processes. Neither artificially induced nor natural freeze-thaw processes are well understood in fine-grained materials which give rise to the most difficulty. It is known that the variation of pore pressures at or near the frost line is an important factor in controlling the influences of freezing and thawing on soils and rocks. Research into thaw-consolidation is underway and field measurements of pore pressure effects will be included. The results of this study will contribute to the development of more rational design procedures for foundations of various structures and to our understanding of the mechanics of various periglacial processes.

Contact: N. R. Morgenstern

LANDSLIDE STUDIES

Slope instability in the presence of melting ground ice constitutes a serious impediment to the development of communities and transportation systems in the North. The mechanisms of landslides associated with permafrost are not well understood. Both field and

theoretical studies of these processes are being undertaken with special emphasis on the features found in the Mackenzie Valley.

Contact; N. R. Morgenstern

THERMAL REGIME NEAR PIPELINES

Among the many problems associated with a changing thermal regime in permafrost, one that has generated a good deal of interest is the treatment of conditions near a pipeline. In this it is necessary to recognize the mutual interaction of the thermal regimes inside and outside the pipe. Temperatures inside the pipe determine the fluid viscosity, reaction and precipitation rates, etc. Outside the pipe, the structural integrity of the surrounding medium is strongly affected by thawing conditions.

A mathematical representation of either steady or transient conditions in and near an active pipeline has been developed in the Department of Chemical and Petroleum Engineering: this representation is available for practical application. Studies to investigate practical techniques for the minimization of the disturbing thermal effect of a pipeline are being pursued.

The Department of Mechanical Engineering undertook a study of this and related problems with special emphasis being placed on the development of numerical solutions. The results have been useful in describing the shape and extent of thaw zones as they are affected by such factors as ambient and pipe wall temperatures.

Contact: W. Nader or G. S. H. Lock

FOUNDATION ENGINEERING

Foundation systems in frozen ground require special consideration if they are to function well. Novel design problems occur due to the need for considering thermal effects, heaving phenomena and the rheological properties of frozen ground. Since parts of the Canadian Arctic are highly seismic, earthquake loading must also be considered.

Research programmes are currently being planned to determine optimum foundation systems for the different environments and loading conditions encountered in northern development.

Contact: N. R. Morgenstern or S. Thomson

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ENVIRONMENTAL ENGINEERING

The mutual interaction of the environment and engineering systems.

BIOLOGICAL ACTIVITY UNDER ICE

The development of northern areas (Arctic and sub-Arctic) has exerted, and will continue to exert, an increasing demand on the environment in those areas. Because of the long winters, and the short summer growing season, the effect of man's activities on the environment is much more pronounced and of longer duration than in the temperate or tropical zones. Recovery rates are so low that permanent effects are feared.

In so far as stream and lake pollution are concerned the assessment of biological activity under ice cover is of prime importance in the Arctic. There are two facets associated with the problem, viz. the longevity of pathogenic organisms, and the oxygen demand of organic wastes.

It may be felt that because of the large volumes and areas of water present in Northern Canada, pollution problems are minimized because of the dilution provided. There are certain factors which negate this line of reasoning.

The presence of water transportation creates the possibility—in fact the probability—that waters, particularly in docking areas, are contaminated if not polluted. Residents of the area have been accustomed to drinking untreated river water and are thus liable to contract water-borne diseases.

While the cold water is generally conducive to low rates of decomposition, studies of the rivers in Alberta have shown that with a suitable catalyst, present in the form of slime-covered contact areas, biological activity rates greatly exceed that which might be expected. The lack of reaeration compounds the problem.

In some streams the dissolved oxygen content is much below saturation values during the winter period because of natural factors.

The treatment of wastes also poses problems. Treatment efficiencies are lower at the predominating lower temperatures. Aside from the biological aspects there are problems of operation of treatment units in isolated communities where skilled personnel are not available and repairs are difficult to make or obtain. The supply of water and the collection of water are in themselves major problems, which require much ingenuity of design to ensure reliable systems which are economically feasible.

Contact: P. H. Bouthillier

ICE FORMATION AND MELTING

The Ablation of Ice by a Water Jet

The ablation of an ice surface by a jet of warm water was studied under laboratory conditions. Of particular interest for this study was the rate of ablation and the shape of the cavity formed in the ice for various jet conditions. The motivation of this work was a better under-

standing of a basic ablation problem; however, some of the results may have practical implications for the use of water jets in the cutting or drilling of ice.

Contact: R. R. Gilpin

Ice Formation in Pipes

Among the great variety of circumstances under which solidification in cylindrical geometries is of interest e.g. casting of metals, freezing of foods, etc., the situation of greatest interest in northern regions is the maintenance of a piped water supply. Whether the pipe is located underground in a region of sporadic permafrost or situated in a cold meteorological environment, interest centres around the formation of an annulus of ice. The effect of this annulus on flow rate and pressure drop is of obvious importance.

In the Department of Mechanical Engineering, work on ice formation in pipes began in 1966 and constitutes a continuing research programme. In essence this programme is aimed at uncovering the effect of flow rate and inlet temperature on the rate of ice formation. The effect of heat transfer conditions on the outside of the pipe is also being considered. The work consists of both mathematical and experimental studies.

A test rig was constructed in 1967 for the study: the working section is a 3.0 ft. length of 3.0 ins. diameter pipe cooled by a liquid refrigerant. The rig has undergone continuous modification and is being used to study the effect of pipe inclination on the rate of ice formation. Measurements of ice thickness have been taken by two very distinct techniques. In the first of these the tip of a mechanism locates the ice-water interface by direct contact: previous calibration of the mechanism motion thus enables the interface to be located. The second technique employs an ultra-sonic sensor which measures the distance from the interface to the sensor in terms of the time lapse between an emitted and received pulse. A third technique, which combines the other two, is under investigation.

Contact: G. S. H. Lock

Frazil Ice Formation in Water Mains

Under some conditions ice growth does not proceed by the normal one-dimensional crystallization mechanism that produces ice layers but proceeds by the formation of ice crystals interspersed in the water medium. When this form of ice, called frazil, forms in a water main the flow of water is stopped much more quickly than when layered ice forms. The conditions under which frazil ice is formed and their effects on the amount and structure of the resulting ice are being studied.

Contact: R. R. Gilpin

RIVERS AND LAKES

Fluvial Processes in Northern Rivers

The construction of roads, railways, pipelines and hydro-electric developments all involve the design of river engineering works and

interferences with rivers which can only be done properly on the basis of an understanding of the fluvial processes active in a given river. The planning of major interferences now often involves environmental impact studies, which should include estimates of probable upstream and downstream effects on the river channel and therefore again requires an understanding of river processes.

Northern rivers differ in several important aspects, (e.g. ice action, predominance of gravel beds, permafrost effects, etc.) from the better documented sand-bed rivers of more southern regions.

The Department of Civil Engineering is conducting research in river engineering under the auspices of a cooperative program with the Research Council of Alberta, the Water Resources Division of the Alberta Dept. of the Environment and the Bridge Branch of the Dept. of Highways and Transport.

Several extensive field studies dealing with sediment transport, scour, channel dimensions and other properties of gravel bed rivers have recently been completed. An investigation into dispersion processes in rivers under open water and under ice conditions is presently in progress. Also in progress is a long-term study of the downstream effects on river regime of regulating northern rivers. Preliminary results are in press.

An investigation of ice impact forces on bridge piers by the Research Council of Alberta is also part of the cooperative program. Two piers have been modified and instrumented. The analyzed results of six years of data collection are available.

Contact: R. Kellerhals or C. R. Neill

Radiative Heating of Ice and Water

Solar heating has an important effect on the thermal structure of ice covered lakes. The absorbed solar energy effectively produces a distributed heat source in the ice and water. Laboratory experiments have been carried out to determine the nature of the distributed heat source and its effect on the temperature distribution in the medium.

Contact: R. R. Gilpin

MICRO CLIMATIC PHENOMENA

Ground Temperature Prediction

A one-dimensional model of the ground and its surface has been developed for northern climates. The model uses a balance of energy fluxes at the ground surface as the boundary condition there. This model has been used to determine a matrix of influence coefficients which relate changes in the various surface cover, soil and meteorological parameters to changes in surface and ground temperatures and active layer depth. These influence coefficients can then be used to estimate the effects of various disturbances on the ground thermal regime.

Contact: R. R. Gilpin

Snow Drifting

The problem of snow drift accumulation around structures located in northern regions will be a critical problem in determining the design and site location of various facilities. Among the systems of current interest which are appropriate for simulation are; drift accumulation around petroleum storage tanks and pipelines, and the effectiveness of snowfence designs in preventing snow buildup on northern airfields. Because field studies of snow drift accumulation are usually impractical, it is desirable to carry out tests on scale models of structures and topographical features under snow drifting conditions.

Drift accumulation is generated by two processes. The first is the accumulation of snow in regions in the lee of structures during a snow storm period, and the second is by the process of saltation, in which snow particles are eroded from an existing surface and moved by wind forces to accumulate at some downwind location. By correctly modelling the particle sizes and atmospheric wind parameters it is possible to accurately simulate both of these drifting mechanisms in the laboratory. The process of abrasion reduces the original dendritic form of snow flakes to ice particles with an almost spherical shape, which can be accurately modelled by a suitably chosen granular material.

Contact: D. J. Wilson

Atmospheric Frost and Ice

It is well known that the presence of moisture in a cold environment often leads to the undesirable formation of frost or ice on a variety of surfaces; land-based, air-borne and sea-borne. Coatings of frost or ice thus formed can alter the function of the component to which the surface belongs and often threatens structural integrity.

In 1971, an extensive series of experiments were initiated using the FROST* tunnel built in the Department of Mechanical Engineering. This facility is a low speed (up to 150 ft/sec) steady-flow, closed-circuit tunnel in which air temperatures can be maintained well below zero. The test section is 36 ins. long and about 18 ins. wide, thus permitting both full scale and model studies. Projects of current interest include accretion on the outside of a cylinder and ice formation on the inside of a pipe situated in a cold cross-flow.

The first work completed in the FROST tunnel consisted of a study of shipboard icing resulting from freezing sea spray. The study revealed the importance of the principal parameters and variables and led to suggestions as to how trawler icing could be minimized.

Contact: G. S. H. Lock

MATERIAL PROPERTIES AT LOW TEMPERATURE

Low-Temperature Behaviour of Asphalt Pavements

Cracking of asphaltic concrete pavement surfaces induced by low temperatures has been a problem of considerable concern for several years. In Canada, and particularly in the three prairie provinces, much

* Fundamental Research On Solidification and Thawing.

effort has been expended in determining the causes of this problem and in attempting to devise economical solutions. Extensive surveys of the main highway system in the Province of Alberta have pointed out the ubiquity of the situation and have generally indicated that larger amounts of transverse cracking appear to be associated with certain asphalt sources. Presently-available procedures for the design, testing and evaluation of the pavement components are not directly applicable to low temperature behaviour, and therefore are inadequate in defining the characteristics of the pavement system at the temperature conditions conducive to cracking.

Continuing investigations of these problems are being made under the Alberta Co-operative Highway Research Program, in which the Department of Civil Engineering participates jointly with the provincial Department of Highways and Transport and the Alberta Research Council.

Past work has primarily involved documenting the extent of cracking in asphalt pavements and relating this to measured characteristics of the asphalt cement and asphaltic concrete mixtures. Present work includes detailed assessment of actual pavement thermal regimes from recorded data and predicted regimes based on numerical solution techniques using meteorological data. It is expected to incorporate the previous work into a feasible design subsystem for asphalt pavements subjected to low temperatures.

Facilities are available for examination of asphalt cements and asphaltic concrete mixtures throughout realistic working temperature ranges for pavements in northern regions. Specialized equipment has been developed for evaluating the tensile properties of asphaltic concrete at low temperatures.

Contact: K. O. Anderson

Thermal Insulation

The thermal properties of dry insulating materials have been documented at temperatures above zero. However, thermal conductivity may be altered by the presence of moisture in the insulation and little information is available on the effect of moisture when the temperature is below freezing. Vapor barriers may be adequate when low temperature periods are of short duration but the effect of moisture on insulation over long periods at low temperatures is not available.

The Department of Mechanical Engineering hopes to develop equipment for the measurement of thermal conductivity in situations where low heat flux is present and temperatures are below —50°F. The first work will involve dry insulation and later work will investigate the effect of moisture on the thermal conductivity.

Contact: G. W. Sadler

Fracture Mechanics

It is well known that temperature, and in particular a temperature below 20°F, has a very strong influence on the fracture of engineering materials. The fractures which occur in common materials such as steel and aluminum are severely affected by temperatures encountered

in northern Canada. The design of engineering structures to withstand the effects of these temperatures is presently in a state of flux. The previously accepted tests, e.g. charpy energy absorption criteria, are now suspect. There is, in fact, no accepted criterion for cold weather design.

The Department of Mechanical Engineering is currently studying the application of fracture mechanics to the prediction of possible failure in medium strength steels and plastics used in the construction and pipeline industry. In particular, several methods are being investigated for the evaluation of a material property known as the stress intensity factor to determine whether or not this parameter can be used to predict failure or the conditions under which failure may be expected. Hopefully, this parameter will permit the prediction of the smallest acceptable flaw size, the effects of temperature on the material, the effects of welding and other metallurgical damage on the design parameters of the material. In addition it will help in the selection of inspection criteria and acceptability standards as well as suggest non-destructive testing methods.

Contact: G. Ford

Metallurgy

Engineering and research activities in metallurgy include the effects of chemical and thermal environments on the mechanical properties of metals, alloys and structural ceramic materials. Among these are stress corrosion, corrosion fatigue, ductile and brittle fracture, and wear. These topics have already been the subject of research efforts; some are presently in progress and others have led to publications.

Presently, metallurgical variables in pipe line steels such as chemical composition, rolling practice and their effect on the resistance to crack propagation are being studied in a temperature range from -50°C to +70°C. It is planned to extend this work to include the effects of gaseous environment and of welding on crack propagation at low temperatures.

Relevant facilities which are available for research in the Department of Mining and Metallurgy are: Instron Universal Test Instrument, Environmental Test Chamber, Multiple Stress Corrosion Test Facility, X-ray Diffraction and X-ray Fluorescence Instruments, Metallographic facilities, Electron Microscope, Friction Tester for controlled environment, Dilatometer for accurate measurement of thermal expansion.

Contact: F. H. Vitovec

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RESOURCE DEVELOPMENT

Exploration, production and management of resources

MINERAL EXPLORATION, MINING AND BENEFICIATION

In the past, the mineral industry has been the major producer of new wealth in northern Canada, and much of the future activity in this area will be based on the development of its mineral resources. Therefore the members of the Department of Mining and Metallurgy have, since its inception, been closely interested in the mineral industry of northern Canada. Several of the staff have been involved for many years in exploration and mine development and mineral beneficiation projects as resident engineers and consultants.

A well-equipped rock mechanics laboratory is in use for the study of the mechanical properties of rocks. Mineral beneficiation studies on ores from northern Canada have been carried out and the Department is well equipped to test or develop methods for processing almost all kinds of mineral deposits.

Contact: L. R. Plitt or T. H. Patching

PETROLEUM EXPLOITATION

Although petroleum production in northern Canada began almost fifty years ago, there is still much to be learned before optimal long-term conservation methods can be developed and designed. Engineering research to date has been grossly insufficient though it is anticipated that it will become intensified in certain specific problem areas.

Central in these problem areas is the effect of heat transfer in and around the well bore. This situation has some similarity with the pipeline problem situation discussed previously (GEOTECHNOLOGY) but does contain essential differences. The drilling and completion stages, for example, must be executed in such a way that any heat generated produces the minimum effect on the frozen surroundings whilst at the same time allowing installation of an adequately competent cement sheath.

The Department of Chemical and Petroleum Engineering has a long-standing interest in these and related problems. For example, preliminary results have been obtained and investigations are continuing in several areas, including:

(i) The estimation of bottomhole pressure when heat transfer between fluid and surroundings is significant.

(ii) The effect of wellbore heat losses on steam injection.

Contact: P. M. Dranchuk

RISK ANALYSIS IN CAPITAL INVESTMENT DECISIONS

The purpose of the study is to create a realistic approach for the measurement of the risks involved in capital investment decisions associated with the exploration, drilling, and producing problems of the petroleum industry in northern Canada.

Within the broad framework stated, a project of particular interest is the development of a model that would have some practical application to a petroleum company operating in northern Canada.

The method of risk analysis proposed would recognize the probabilistic nature of the variables affecting the profitability of the investment. The method would combine the distribution of each variable into a final single profitability distribution.

The 360-67 computer system on campus will be used extensively during this research.

Contact: J. C. Sprague

REAL-TIME COMPUTER APPLICATIONS

In northern installations the usual justification for real-time computer applications is strengthened by the rigorous climate and the usual desire to reduce skilled manpower requirements. Typical installations include unattended operation of oil and gas wells or pipeline pumping stations; automated analysis techniques in quality control laboratories of resource industries; process control and monitoring of producing plants; and centralized supervision of plant operations and service functions including sheduling, start-up, shutdown and regulation of utilities such as heat, power and pollution control units. However, the major function other than manpower reduction is to act as the "sensors" or collecting mechanism for an information system that permits all management, sheduling and planning functions to be done at centralized corporate or government centres rather than on-site.

The Department of Chemical and Petroleum Engineering operates a "Data Acquisition, Control and Simulation (DACS) Centre" dedicated to the development of theoretical and practical techniques for industrial and research applications. Facilities include an IBM 1800 digital computer operating in a time-shared, multi-programming mode, a DEC PDP-81 computer supervising a system of remote terminals, and EAI 590 hybrid computing facilities. Since the Centre opened in 1967 applications have included direct digital control (DDC), supervisory control, gas chromatograph and IR analyser monitoring, and system documentation. A booklet is available from the Centre describing the facilities, applications, courses offered, reports and programs available, etc.

Contact: D. G. Fisher

ARCTIC LAND USE RESEARCH (ALUR)

In cooperation with the universities of British Columbia and Saskatchewan, the Department of Civil Engineering is engaged in a study of the effects on different types of land use on the regimes of rivers in the northwestern portion of Canada. The study, sponsored by the Department of Indian Affairs and Northern Development, consists of:

1. Classification of the precipitation regime.
2. Classification of the river discharge regime.

3. Ice break-up, freeze-up and thickness analysis.
4. Determination of river bank erosion, in northern rivers.
5. Monitoring of river flow data in 10 small watersheds in the Watson Lake area.

Contact: J. P. Verschuren

PIPELINE CONVECTION STUDIES

Accurate prediction of pressure drop and heat transfer through the pipe wall is required for the safe design and operation of the arctic pipeline proposed for the transportation of arctic crude oil and natural gas. The design considerations for hot oil pipelines are characteristically different from those for cold gas lines. Similarly, the design of water mains which do not freeze in Canadian northern regions with continuous or discontinuous permafrost requires an accurate knowledge of flow and heat transfer characteristics. With these applications in mind, a study of various factors affecting the pressure drop and heat transfer for fluid flow in pipes under various possible arctic conditions has been initiated with operating grants from the National Research Council of Canada and the Petroleum Education Aid Fund of Alberta. The factors to be investigated are:

1. Viscous dissipation effect.
2. Free convection effect.
3. Viscous dissipation, pressure work and Joule-Thomson effects for gas flows.
4. Pipe inclination effect.
5. Variable viscosity effect.

Contact: K. C. Cheng

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